836-A-15
NAS1.60:1479
COMPLETED
OCT - 7 1979

NASA Technical Paper 1479

A Summation and Inhibition Model of Annoyance Response to Multiple Community Noise Sources

Clemans A. Powell

ORIGINAL

SEPTEMBER 1979

NASA

23

NASA Technical Paper 1479

A Summation and Inhibition Model of Annoyance Response to Multiple Community Noise Sources

Clemans A. Powell
Langley Research Center
Hampton, Virginia

National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

1979

SUMMARY

A model of annoyance due to combined noise sources has been developed. The model provides for the summation of the subjective magnitudes of annoyance due to the separate noise sources and for the inhibition of the subjective magnitudes of each source by the presence of the other noise sources. The inhibition process is assumed to mathematically obey a power-group transformation.

The results of an experiment in which subjects judged the annoyance of 15-minute sessions of combined aircraft and road-traffic noise are compared with the model herein developed and with several other models of combined source annoyance. These comparisons indicated that the model developed herein provides better qualitative and quantitative agreement with experimental responses than the other models. The application of the model to multiple community noises is discussed.

INTRODUCTION

A major problem in the prediction of community annoyance response to environmental noise is how to quantify noise environments which contain more than one noise source. One recent approach (refs. 1 and 2) is to express the noise exposure in terms of the A-weighted energy-equivalent continuous sound level L_{eq} or its derivative measure L_{dn}, which incorporates a night exposure penalty. Although the unique dose-response relationship implied by such an "energy" model is appealing because of its simplicity, there is considerable evidence (refs. 3 to 7) which indicates that it cannot accurately predict annoyance response to all noise environment situations. For example, the findings of reference 3 indicated that equal exposures (in terms of L_{eq}) to different noise sources do not necessarily evoke equal annoyance responses. In addition, references 4 to 6 indicated that annoyance response to one source is inhibited by the presence of other noise sources. It was further shown in references 5 and 7 that general noise dissatisfaction, or total annoyance, with exposures to combinations of different noise sources could not be satisfactorily explained by an energy model. Consequently, the present models apparently are not entirely adequate for predicting community response to noise environments which contain multiple noise sources.

It is the purpose of this paper to present a proposed model of annoyance response to combined noise sources which takes into account the interactions between noise sources such as those found in the experiments in reference 7. The proposed model provides for summation of annoyance due to the separate noise sources and for inhibition of annoyance due to each source by the presence of the other sources. The assumptions and procedures used to derive the model are presented in detail. The suitability of the model is examined by comparing it and several other models with the results of an experiment reported in reference 8.

SYMBOLS

A,a,B,b,c	constants used in developing mathematical model of annoyance due to combined noise sources
f	functional relationship of annoyance to noise level
J	mean subjective judgment
k	constant in the general psychophysical law
L_{eq}	equivalent continuous sound level (energy-averaged, A-weighted), dB
R	community annoyance response to noise
β	exponent in general psychophysical law
η,κ	constants in a power-group transformation
ϕ	intensity of stimulus
ϕ_o	intensity of stimulus at threshold of perception
Ψ	subjective magnitude of stimulus
Ψ'	inhibited subjective magnitude of stimulus

Subscripts:

1	stimulus 1
2	stimulus 2
a/c	aircraft
d	dominant noise source
r/t	road traffic
s	subordinate noise source
t	total

Note that more details of the indices and scales for acoustical measurements can be found in a number of general noise references, including reference 9.

MODEL DEVELOPMENT

The following sections describe the steps leading to the development of a model of annoyance response to combined noise sources. The first step was to provide a means for describing the inhibition in sensation magnitude of each

individual noise source, or stimulus, by the presence of another source. The second step was to assume a reasonable rule for combining the magnitudes of the inhibited stimuli. The final step involved making several simplifying assumptions and performing the necessary algebraic manipulations to reduce the relationships resulting from the first two steps into a convenient form.

Background

A form of the general psychophysical law relating the sensation magnitude of a stimulus to a physical measure of its intensity is (ref. 10)

$$\Psi = k(\phi - \phi_o)^{\beta} \tag{1}$$

where Ψ is the sensation magnitude expressed along a continuous scale having ratio properties, ϕ is the intensity of the stimulus, and ϕ_o is the intensity at the effective threshold of perception of the stimulus. The constant k depends on the measurement unit of ϕ, and the exponent β depends on the sense modality of the stimulus.

It was proposed in reference 10 that the sensation magnitude of a stimulus is inhibited by the presence of an additional stimulus and that this inhibition could be mathematically represented by a power-group transformation; that is,

$$\Psi' = \kappa\Psi^{\eta} \tag{2}$$

where Ψ' is the inhibited sensation magnitude and Ψ the uninhibited sensation magnitude of the stimulus. The variables κ and η are positive and depend on the intensity and spectral characteristics of the inhibiting stimulus.

The proposal to use the power transformation was based on a review of many studies of the inhibition of both auditory and visual stimuli. The basic inhibition phenomenon observed in these studies is illustrated in figure 1. The dashed line of figure 1 represents the relationship, determined in subjective tests, of the sensation magnitude of a target stimulus to its intensity level. The dotted curve represents, in a general sense, experimentally observed sensation, or "subjective" magnitude, of the target stimulus when an inhibiting stimulus of fixed intensity is present (an example can be found in refs. 11 and 12). The solid line represents the power transformation suggested in reference 10. The data presented in reference 10 indicate that the break point in the solid line occurs generally at a point where the uninhibited subjective magnitude of the target stimulus is somewhat greater than the subjective magnitude of the inhibiting stimulus. The general trend of the data from references 11 and 12, however, indicates small but measurable inhibition for even greater subjective magnitudes of the target stimulus. This is accounted for in the following section which describes how the power-transformation theory of reference 10 in a modified form was used as a mathematical basis for the inhibition process proposed in the present model.

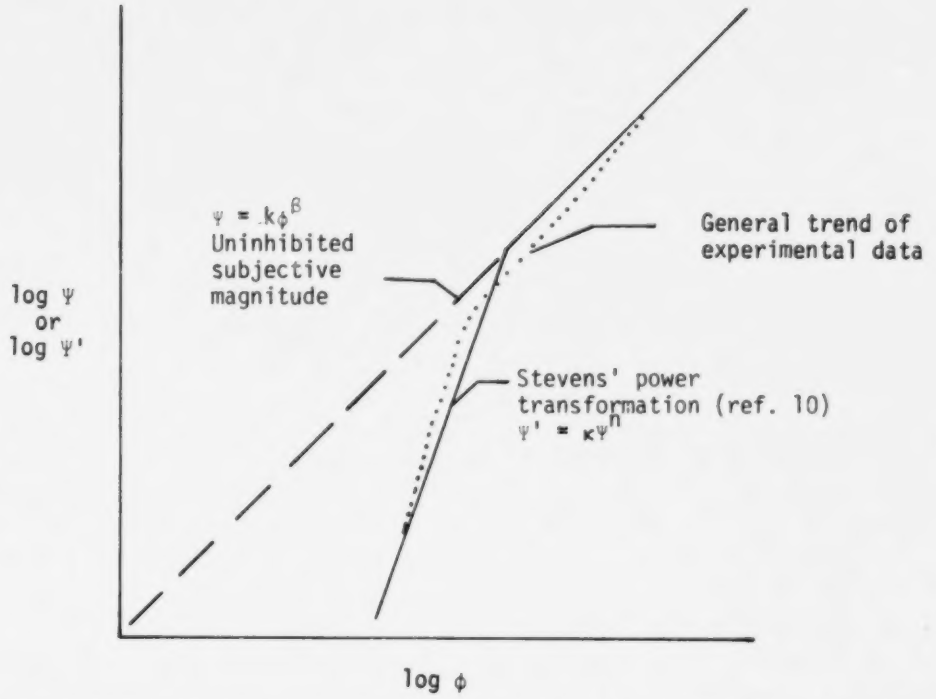


Figure 1.- Generalized relationships of inhibited and uninhibited subjective magnitudes of a stimulus to intensity of the stimulus.

Model Approach

Inhibition.- For two noise sources at levels sufficiently above their effective thresholds, the independent subjective magnitude of each source can be assumed to be related to their respective physical intensities by

$$\Psi_1 = k_1\phi_1^{\beta} \tag{3}$$

and

$$\Psi_2 = k_2\phi_2^{\beta} \tag{4}$$

The choice of separate constants, k_1 and k_2, provides for conditions in which equal intensity levels of the two sources do not necessarily evoke equal annoyance responses. The choice of the single exponent, β, assumes that the growth of annoyance with intensity is constant for the sources and depends solely on the sense modality.

If one stimulus is assumed to have constant intensity ϕ_2, the subjective magnitude Ψ_2 is given by equation (4). Now if the intensity of the other target stimulus is allowed to vary, the inhibited subjective magnitude of the target stimulus Ψ_1' is assumed to be related to its uninhibited subjective magnitude Ψ_1 as shown in figure 2. In region I, where Ψ_1 is less than Ψ_2, Ψ_1 is highly inhibited and Ψ_1' is given by a power-group transformation.

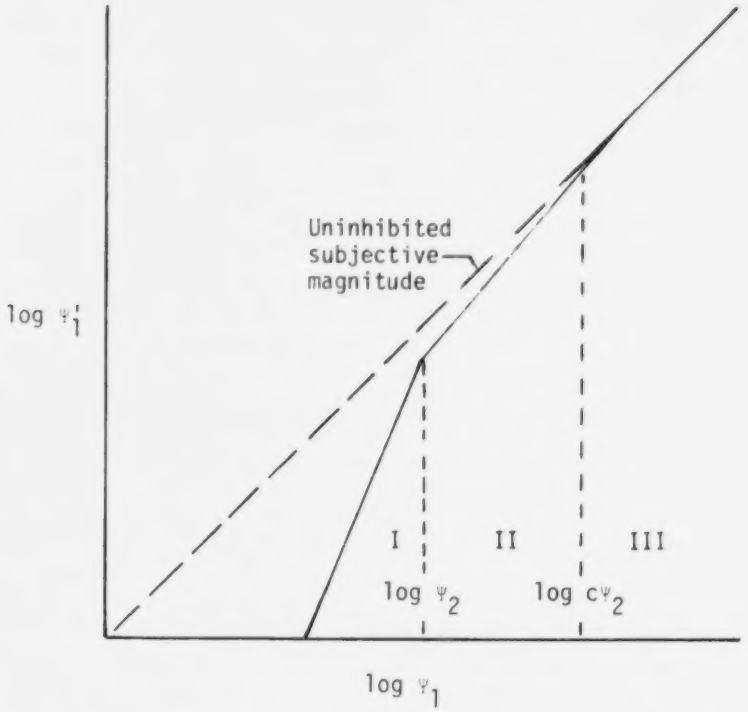


Figure 2.- Relationship between inhibited and uninhibited subjective magnitude of stimulus 1 in the presence of stimulus 2.

In region II, where Ψ_1 is somewhat greater than Ψ_2, Ψ_1 is still inhibited so that Ψ_1' is given by a different power transformation. In region III, where Ψ_1 is greater than some constant c times Ψ_2, no inhibition is present and Ψ_1' is given by Ψ_1. This hypothesized relationship is somewhat different than that proposed in reference 10 and depicted in figure 1, since a second power transformation is assumed for region II. This approach is supported by the results of previous experiments (ref. 8) on the annoyance of individual aircraft noises. Traffic or background noise was found to inhibit the aircraft noise, even though the traffic level was much less than the aircraft peak levels. It has also been found in references 11 and 12 that some loudness masking occurs for stimulus levels considerably greater than the masking level. The inclusion of the power transformation in region II thereby represents this generally observed phenomenon in a mathematically convenient way.

Similarly, if fixed values for ϕ_1 and Ψ_1 are assumed, stimulus 2 should be inhibited with the same type of relationship between its uninhibited and inhibited subjective magnitudes Ψ_2 and Ψ_2'. In either situation, except at the point of subjective equality where $\Psi_1 = \Psi_2$, one source is dominant, in either region II or region III, and the other source is subordinate, in region I.

To simplify the mathematical development of the model, the following change in notation is used: The uninhibited subjective magnitude of the subordinate source is designated as Ψ_s; the uninhibited subjective magnitude of the dominant source is designated as Ψ_d. The corresponding inhibited subjective magnitudes are designated as Ψ_s' and Ψ_d', respectively.

In region I, as depicted in figure 3(a), the inhibited subjective magnitude of the subordinate source can be mathematically represented by

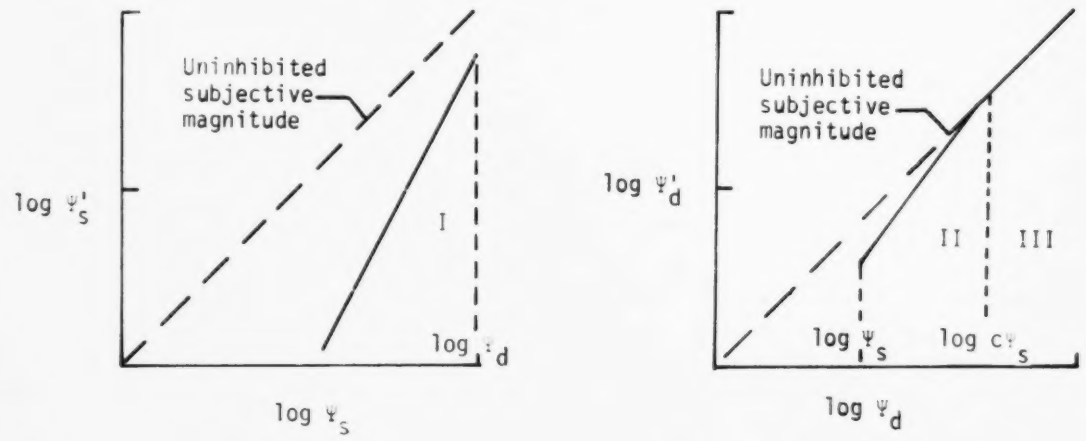
$$\log \Psi_s' = A + (1 + a) \log \Psi_s \tag{5}$$

where A and a are constants for a given value of Ψ_d. The multiplier for $\log \Psi_s$ was chosen to be $(1 + a)$ to indicate that $\log \Psi_s'$ increases more rapidly than does $\log \Psi_s$.

Similarly, in region II, as depicted in figure 3(b), the inhibited subjective magnitude of the dominant source can be mathematically represented by

$$\log \Psi_d' = B + (1 + b) \log \Psi_d \tag{6}$$

where B and b are constants for a given Ψ_s.



(a) In region I.

(b) In regions II and III.

Figure 3.- Graphical representations used to establish relationship between inhibited and uninhibited subjective magnitudes of annoyance.

Of course, in region III, the dominant source is uninhibited; that is,

$$\Psi'_d = \Psi_d \tag{7}$$

Summation.- The primary assumption of the present model is that the total annoyance due to combined noise sources, when expressed as a subjective magnitude with ratio-scale properties, is equal to the addition of the inhibited subjective magnitudes of the component noise sources. The total subjective magnitude of annoyance for the two noise sources is given therefore by

$$\Psi_t = \Psi'_d + \Psi'_s \tag{8}$$

where Ψ'_d and Ψ'_s are the inhibited subjective magnitudes of the dominant and subordinate source, respectively. This summation of the subjective magnitude components is analogous to the methods used in several loudness level or perceived noise level calculation procedures (ref. 9).

Additional assumptions.- The relationships for the inhibited subjective magnitudes (eqs. (5) and (6)), while useful from a conceptual point of view, are not practicable. As was stated earlier, the factors A and a are constants only for a given value of Ψ_d and the factors B and b are constants only for a given value of Ψ_s. To remove these limitations, the following additional assumptions were necessary:

1. The values of the factors a and b are constant over the range of subjective magnitude of interest in community noise exposures.

2. At the point of subjective equality, the inhibited subjective magnitudes are also equal; that is, $\Psi'_d = \Psi'_s$ when $\Psi_d = \Psi_s$.

3. The inhibited subjective magnitudes Ψ'_d and Ψ'_s are piecewise continuous at the boundaries between regions I and II and between regions II and III.

Justification for the first of these assumptions can be found by visually examining data presented in references 10 to 12. Over ranges in sound pressure level of 40 to 90 dB for both target and inhibiting stimuli, it appears that the two-segment inhibition relationship proposed in the present model could be fitted to the experimental data with good accuracy by appropriately changing only the boundary between regions II and III as a function of the inhibiting stimulus.

Justification for the second assumption is not as straightforward. It is known, for example, that loudness masking is frequency dependent. Similarly, community noise sources with large differences in spectral characteristics could also have different annoyance-inhibiting properties. Therefore, the present model may be applicable only to noise sources which have similar spectral characteristics. Although this assumption is a limitation on the scope of the

model, it is not a limitation on the concept of summation and inhibition. It would be possible to adapt the model to noise sources having dissimilar inhibiting properties. However, the assumption of similar inhibiting properties greatly simplifies the mathematical development to follow.

Mathematical development.- At the boundary of regions II and III (see fig. 3(b)), the subjective magnitude of the dominant source is not inhibited by the subordinate source and

$$\Psi_d' \Big|_{\Psi_d = c\Psi_s} = \Psi_d \tag{9}$$

Equation (6) for region II therefore becomes

$$\log c\Psi_s = B + (1 + b) \log c\Psi_s$$

which can be reduced to the form

$$B = -b \log c\Psi_s$$

or

$$B = \log \left[\left(\frac{1}{c} \right)^b \left(\frac{1}{\Psi_s} \right)^b \right] \tag{10}$$

Upon substitution of equation (10) into equation (6), the inhibited subjective magnitude of the dominant source in region II can be expressed by

$$\log \Psi_d' = \log \left[\left(\frac{1}{c} \right)^b \left(\frac{1}{\Psi_s} \right)^b \right] + \log \Psi_d{}^{1+b}$$

or

$$\Psi_d' = \left(\frac{1}{c} \right)^b \left(\frac{\Psi_d}{\Psi_s} \right)^b \Psi_d \tag{11}$$

At the boundary of regions I and II (see fig. 3(a)), the inhibited subjective magnitudes of the subordinate and dominant sources are assumed to be equal:

$$\Psi_s' \Big|_{\Psi_s=\Psi_d} = \Psi_d' \tag{12}$$

Equation (5) for region I therefore becomes

$$\log \Psi_d' \Big|_{\Psi_s=\Psi_d} = A + (1 + a) \log \Psi_d$$

which can be reduced to the form

$$A = \log \Psi_d' \Big|_{\Psi_s=\Psi_d} - (1 + a) \log \Psi_d \tag{13}$$

The inhibited subjective magnitude of the dominant source in region II (eq. (11)) reduces at the boundary between the regions I and II to

$$\Psi_d' \Big|_{\Psi_s=\Psi_d} = \left(\frac{1}{c}\right)^b \Psi_d$$

Substitution of this relationship into equation (13) yields

$$A = \log \left[\left(\frac{1}{c}\right)^b \Psi_d\right] - \log \Psi_d^{1+a}$$

or

$$A = \log \left[\left(\frac{1}{c}\right)^b \left(\frac{1}{\Psi_d}\right)^a\right] \tag{14}$$

Upon substitution of equation (14) into equation (5), the inhibited subjective magnitude of the subordinate source in region I can be expressed by

$$\log \Psi_s' = \log \left[\left(\frac{1}{c}\right)^b \left(\frac{1}{\Psi_d}\right)^a\right] + \log \Psi_s^{1+a}$$

or

$$\Psi_s' = \left(\frac{1}{c}\right)^b \left(\frac{\Psi_s}{\Psi_d}\right)^a \Psi_s \tag{15}$$

The total subjective magnitude of annoyance for the combination of subordinate and dominant sources is therefore obtained from equations (7), (8), (11), and (15). For $\Psi_d \geq c\Psi_s$, the dominant source is in region III (the subordinate source is always in region I), so that Ψ_t' is given by

$$\Psi_t = \Psi_d + \left(\frac{1}{c}\right)^b \left(\frac{\Psi_s}{\Psi_d}\right)^a \Psi_s \qquad \left(\frac{\Psi_d}{\Psi_s} \leq c\right) \tag{16}$$

For $\Psi_d < c\Psi_s$, the dominant source is in region II, so that

$$\Psi_t = \left(\frac{1}{c}\right)^b \left(\frac{\Psi_d}{\Psi_s}\right)^b \Psi_d + \left(\frac{1}{c}\right)^b \left(\frac{\Psi_s}{\Psi_d}\right)^a \Psi_s \qquad \left(\frac{\Psi_d}{\Psi_s} > c\right) \tag{17}$$

COMPARISON OF MODEL WITH EXPERIMENTAL DATA

Description of Experiment

To provide the necessary information to verify the summation and inhibition model, a laboratory experiment was conducted in which subjects made annoyance judgments of extended sessions of multiple-aircraft and traffic noise. A complete description of the design and results of the experiment is reported in reference 8.

The experiment was conducted in a simulated living room in the interior effects room at the Langley aircraft noise reduction laboratory. A total of 17 different noise conditions were used. Each noise condition was of 15-minute duration. For four of the conditions, eight recorded aircraft flyover noises were presented so that the energy-equivalent continuous A-weighted sound levels L_{eq} for the conditions were 30, 40, 50, and 60 dB. Similarly, for four of the conditions, recordings of heavy-flow road-traffic noise, with standard deviation in level of 1.4 dB, were presented at L_{eq} of 30, 40, 50, and 60 dB. The remaining nine conditions consisted of the factorial combinations of the same aircraft and traffic noises at levels of 40, 50, and 60 dB.

While engaged in a leisure activity (such as reading or knitting), subjects (16 groups of 4) made a single, total annoyance judgment of each of 9 sessions

of noise. The judgments were made on numerical category scales from 0 to 9 with the end points labeled "Not Annoying at All" and "Extremely Annoying." Each subject group was exposed to three each of the separate aircraft and traffic conditions and three of the combined noise conditions.

The mean annoyance response to the different noise conditions are presented in table I. Analyses of variance (see ref. 8) performed on the subjects' responses indicated that for the separate aircraft and traffic conditions, noise type was significant at the 5-percent level and noise level was significant at the 1-percent level. For the combined noise conditions, both aircraft-noise level and traffic-noise level and the interaction of the two were found significant at the 1-percent level.

TABLE I.- MEAN RESPONSE AND SUBJECTIVE MAGNITUDES FOR EXPERIMENTAL NOISE CONDITIONS

[Experiment reported in reference 8]

Aircraft noise level, L_{eq}, dB	Traffic noise level, L_{eq}, dB	Mean response (a)	Subjective magnitude
30	---	0.84	0.64
40	---	1.88	1.56
50	---	2.51	2.17
60	---	4.51	4.31
---	30	.68	.51
---	40	1.23	1.01
---	50	2.35	2.01
---	60	4.24	4.00
40	40	2.56	2.22
40	50	2.29	1.95
40	60	5.59	5.60
50	40	2.42	2.08
50	50	4.29	4.05
50	60	4.93	4.80
60	40	4.47	4.26
60	50	4.26	4.02
60	60	6.52	6.80

[a]Response was made on a category scale from 0 to 9 with end points labeled

0 - Not annoying at all

9 - Extremely annoying

Conversion of Response Data Into Subjective Magnitude

Before the summation and inhibition model of annoyance response to combined noise sources could be verified, it was necessary to convert the mean responses obtained from the category scaling technique into a scale which had the ratio properties of sensation, or subjective, magnitudes. It has been long recognized that auditory subjective attributes, such as loudness and noisiness in general, obey the physchophysical power law that a doubling or halving of the attribute is represented by approximately a 10-dB change in sound pressure level. For this experiment, such a relationship was assumed to describe the annoyance response to the conditions of the separately judged airplane and traffic noises. A subjective magnitude of 1.00 was selected to serve as a standard condition and was assigned to the mean response for the L_{eq} = 40 dB traffic-noise condition. Similarly 0.50 was assigned to the L_{eq} = 30 dB traffic response, 2.00 to the L_{eq} = 50 dB traffic response, and 4.00 to the L_{eq} = 60 dB traffic response. A least-squares second-order polynomial fit was performed with the assigned subjective magnitudes of the traffic noises as the dependent variable and the mean response for the four traffic conditions as the independent variable. The following relationship was determined:

$$\Psi = -0.030 + 0.767J + 0.0431J^2 \tag{18}$$

where Ψ is the predicted subjective magnitude and J is the mean response to traffic noise obtained from the experiment. This relationship is indicated in figure 4.

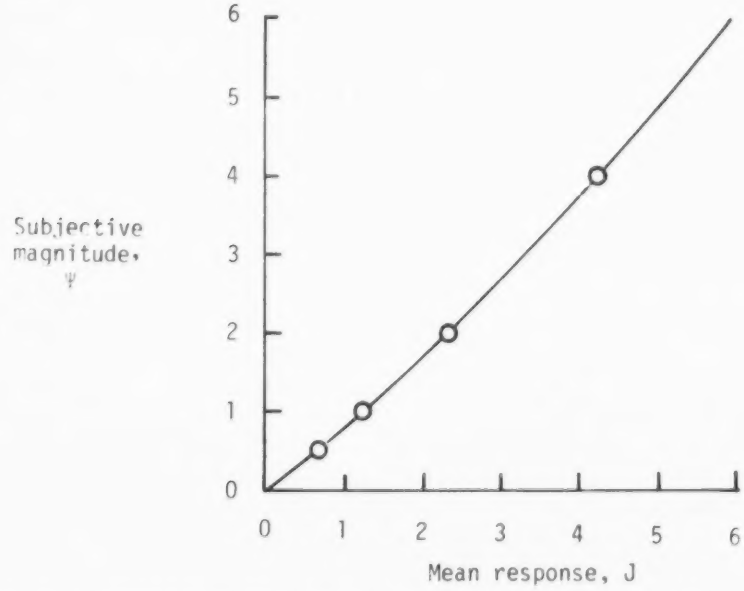


Figure 4.- Relationship between assigned subjective magnitude and mean response for traffic-noise conditions.

Equation (18) was then used to calculate the subjective magnitudes for each of the separate and combined noise conditions. These values are given in table I along with the mean responses.

Comparison of Model With Experimental Data

From the subjective-magnitude data of table I, best estimates of the constants a, b, and c used in the model were found using a three-parameter optimization procedure. The procedure minimized the residual sum of squares between the predicted subjective magnitudes and the calculated subjective magnitudes given in table I for the combined noise conditions. The values of the constants which produced the minimum residual sum of squares were $a = 1.34$, $b = 0.169$, and $c = 2.56$.

Comparisons of the summation and inhibition model with the experimentally determined total subjective magnitudes for the combined noise conditions are presented in normalized form in figures 5 and 6. Figure 5 presents the ratio

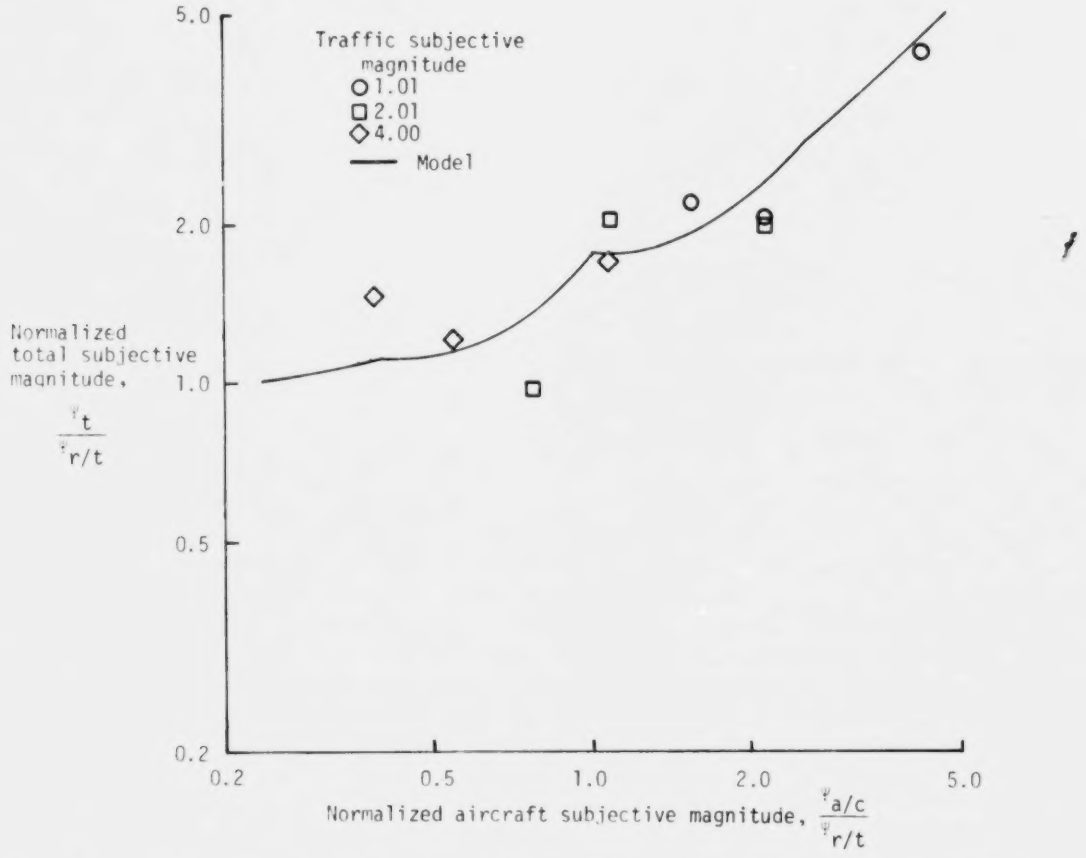


Figure 5.- Comparison of model and experimental data showing relationship between total and aircraft subjective magnitudes both normalized by traffic subjective magnitude.

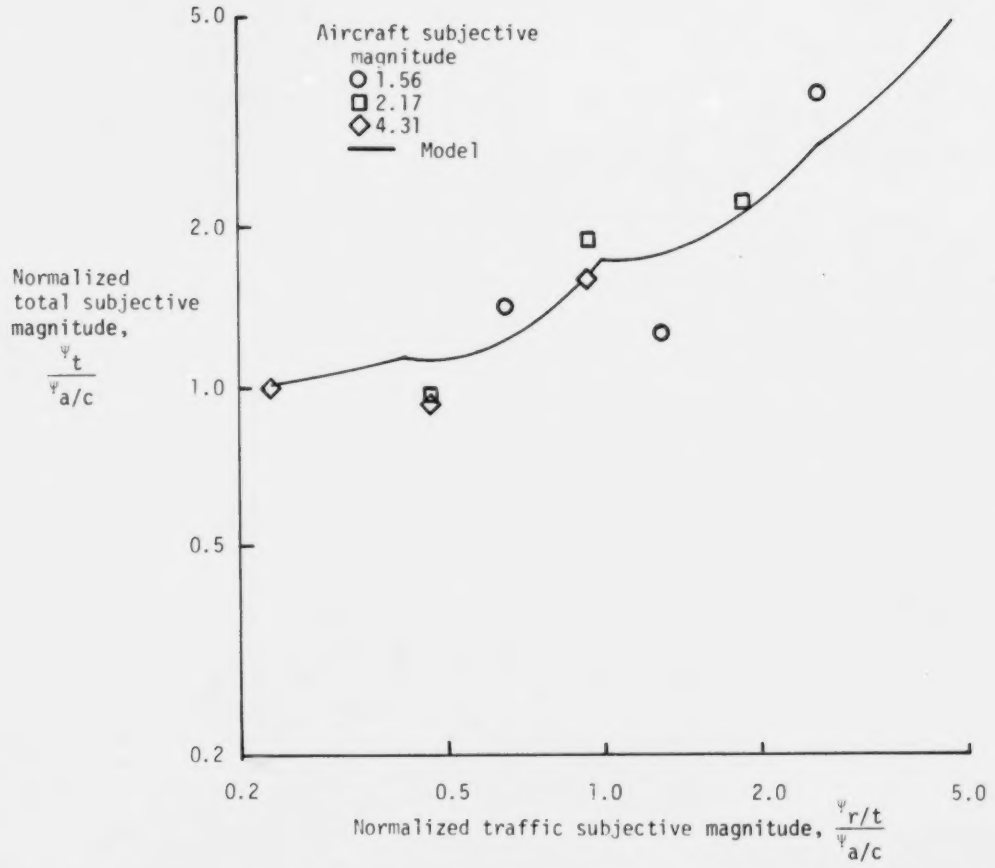


Figure 6.- Comparison of model and experimental data showing relationship between total and traffic subjective magnitudes both normalized by aircraft subjective magnitude.

of total subjective magnitude to traffic-noise subjective magnitude plotted against the ratio of aircraft-noise subjective magnitude to traffic-noise subjective magnitude. The functional relationship indicated by the line was generated from the model and the best fit for the constants a, b, and c. Considering that the subjective-magnitude estimates of both the separate noise conditions and the combined noise conditions included the usual random errors associated with any type of subjective tests and considering that these errors were compounded when combined in the model, the general agreement is good. Figure 6 presents the same data. However, in this case, the normalization was performed using the aircraft-noise subjective magnitudes. Since the model is symmetric about the two noise sources, the same functional relationship is presented in both figures. The data trends of the two figures generally confirm this symmetry and the shape of the curves from the summation and inhibition model.

Comparison With Other Models

Predictions of total annoyance response to the combined noise conditions of reference 8 were made for several other models and are presented in table II.

TABLE II.- SUBJECTIVE MAGNITUDES OF ANNOYANCE DUE TO COMBINED NOISE PREDICTED BY SEVERAL MODELS

Noise levels, L_{eq}, dB		Subjective magnitudes predicted by models				Experimental subjective magnitudes
Aircraft	Traffic	Magnitude summation	Energy summation	Response summation	Summation and inhibition	
40	40	2.57	1.65	1.45	1.88	2.22
40	50	3.91	2.23	3.12	2.74	1.95
40	60	5.56	4.05	5.24	4.37	5.60
50	40	3.18	2.22	2.53	2.41	2.08
50	50	4.18	2.58	3.34	3.42	4.05
50	60	6.17	4.15	5.28	4.60	4.80
60	40	5.32	4.32	4.48	4.42	4.26
60	50	6.32	4.41	4.59	4.80	4.02
60	60	8.31	5.13	5.55	6.81	6.80

The first model used the simple summation of the subjective magnitudes of the separate aircraft and traffic noise conditions to provide the total subjective magnitudes for the combinations. The second model utilized an energy-type summation scheme in which each of the subjective magnitudes of the separate conditions were converted into equivalent energy terms through the appropriate power relationship. The energy values for each combination were subsequently added and the summed energy was then reconverted to obtain total subjective magnitude. The third model is the response summation model of reference 13. In this model the equivalent continuous sound level is augmented by an increment which depends on the differences in noise levels of the separate sources which produce equal annoyance response. Included in table II are the values of the total subjective magnitudes predicted by the summation and inhibition model and those calculated from the response data of reference 8.

Comparisons of the four models and the experimental data are provided in table III. The total sum of squares of the subjective magnitudes of the experimental data for the nine combined noise conditions and the residual sum of squares for each model are presented. The explained sum of squares was obtained by subtracting the residual sum of squares from the total sum of squares. The

coefficient of determination (ratio of explained to total sum of squares) is also presented for each model.

TABLE III.- COMPARISON OF MODELS WITH EXPERIMENTAL DATA

Total sum of squares for experimental data 22.16

	Models			
	Magnitude summation	Energy summation	Response summation	Summation and inhibition
Residual sum of squares	15.76	8.35	4.96	3.43
Explained sum of squares	6.40	13.81	17.20	18.73
Coefficient of determination	0.289	0.623	0.776	0.845

The total annoyance predicted by the magnitude summation model was generally greater than the experimental data. Furthermore, only about 29 percent of the total sum of squares was explained by this type of model. The annoyance predictions given by the energy summation model, on the other hand, generally were less than the experimental data, particularly for those conditions where the levels of, and annoyance response to the separate aircraft and traffic noises were nearly equal. The energy summation model, however, was a great improvement over the magnitude summation model in that it was able to explain about 62 percent of the total sum of squares. The response summation model was an improvement over both previous models in that it was able to explain about 78 percent of the total sum of squares. None of the simple models, however, were as good as the summation and inhibition model which was able to account for about 85 percent of the total sum of squares.

APPLICATION OF THE MODEL

This section describes a method by which the summation and inhibition model can be used to predict the annoyance response to multiple community noise sources. This method involves the computation of a correction factor to be added to the total equivalent continuous sound level to account for the effects of summation and inhibition.

The primary assumption for this method is that although the absolute annoyance responses to two sources are not necessarily equal at equal noise levels, the growth of annoyance with noise level is the same for both sources. This assumption was also made during the development of the present model. For the present discussion, the functional relationship between annoyance response and noise level is assumed to be linear only for illustrative purposes. It is generally found (refs. 3, 8, and 13) that a simple linear transformation of noise level is sufficient to reduce the functional relationship to an invariant form for different types of noise sources. This transformation is indicated in

figure 7. The response to one source at level L_1 is indicated by the solid line and the relationship

$$R_1 = f(L_1) \tag{19}$$

The response to another source at level L_2 is indicated by the dashed line and the relationship

$$R_2 = f(L_2 + D) \tag{20}$$

where D is the difference in level of the two sources for equal annoyance response. The quantity $(L_2 + D)$ represents the "effective level" of the second

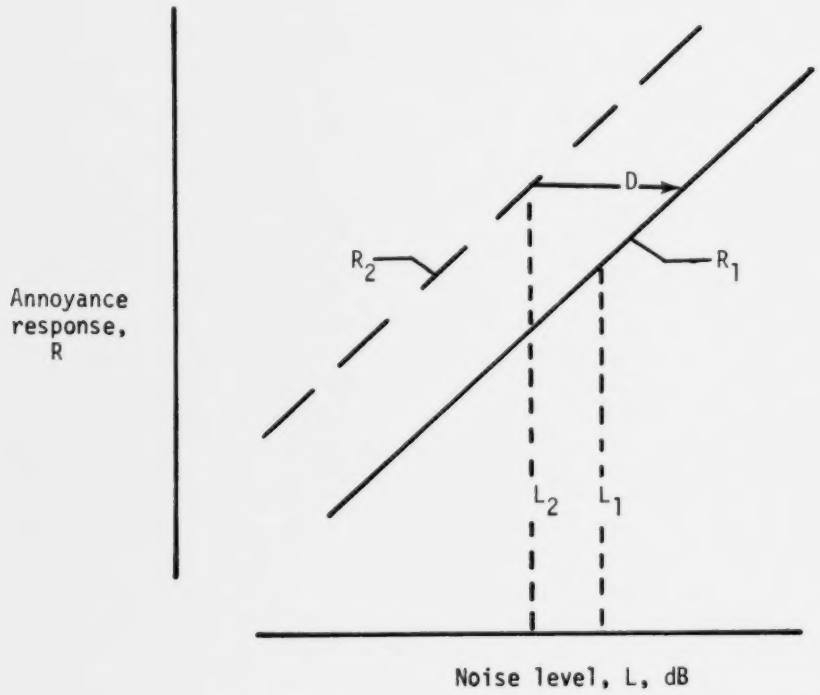


Figure 7.- General relationship between annoyance response and noise level for different sources.

source relative to the first source. The total annoyance response to the combination of the two sources is obtained with the same functional relationship:

$$R_T = f(L_T + E) \tag{21}$$

where L_T is the equivalent continuous sound level of the two sources combined and E is a correction factor to the total noise level to account for summation and inhibition predicted by the present model. The total noise level is given by the energy-type summation

$$L_T = 10 \log \left(10^{L_1/10} + 10^{L_2/10}\right) \tag{22}$$

Values of the correction factor E for several values of D and for a range of differences in levels of the two sources are presented in figure 8. These values were derived from equations (16) and (17); the values of the constants a, b, and c found in the comparison of the model and the experiment (ref. 8) previously described were used and a doubling of annoyance for a 10-dB change in noise level was assumed. The cusps in the curves for constant values of D coincide with points of equal annoyance for the two noise sources and indicate the loci of the greatest deviations of the present model from energy-type summation models.

CONCLUDING REMARKS

A model for predicting annoyance response to combined community noise sources has been developed. This model provides for the summation of annoyance due to separate noise sources and for the inhibition of annoyance of each source by the presence of the other sources. The ability of this model to predict annoyance responses obtained in a recent experiment was significantly greater than that of other candidate models which do not specifically account for inhibition between noise sources.

One possible limitation of the model in its present form is that knowledge of the annoyance of the separate noise sources at equal noise levels is necessary for its use in predicting annoyance to combined noise source situations. Hence, the need exists for future laboratory and field research to provide information on annoyance response to different community noise sources.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
August 1, 1979

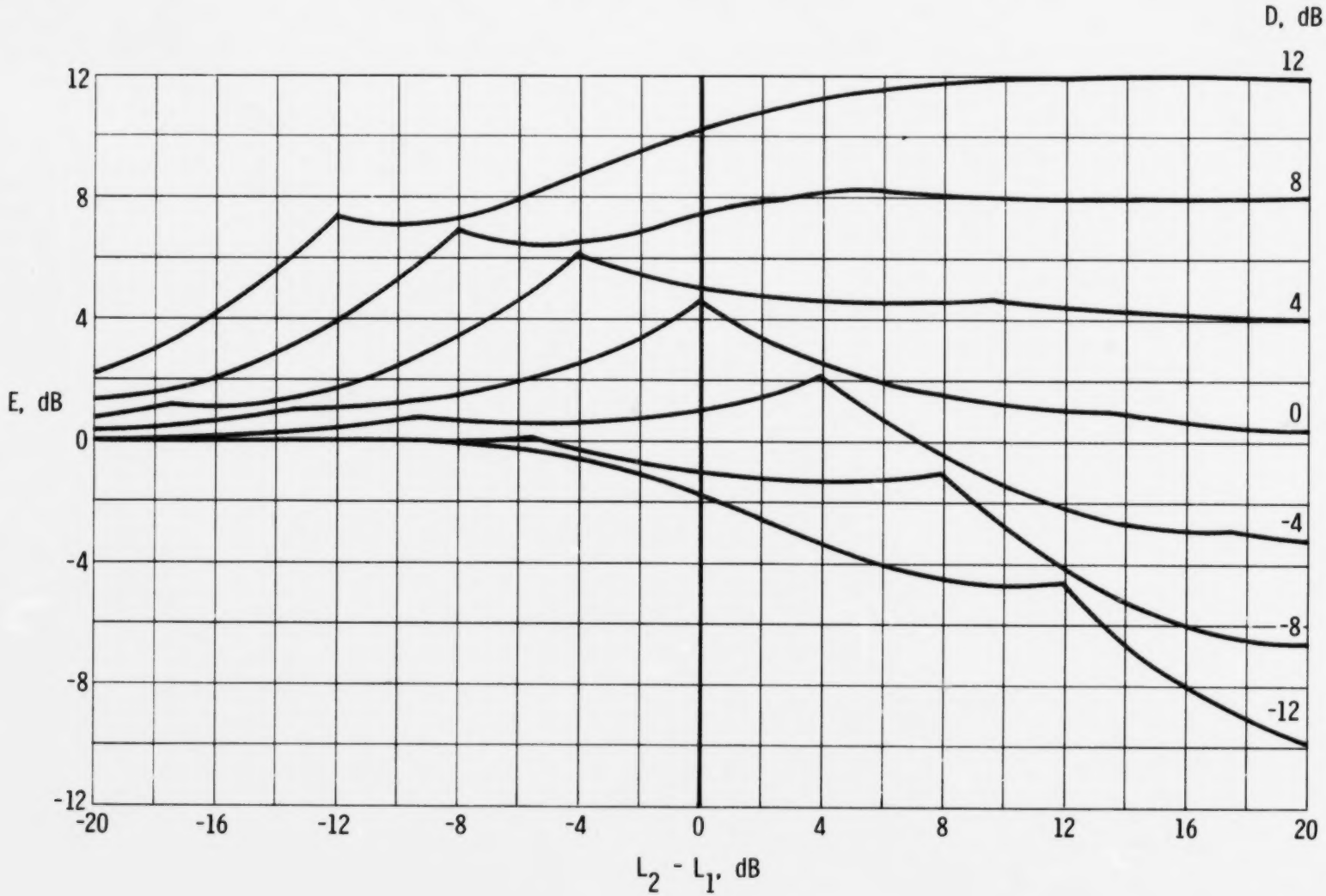


Figure 8.- Correction factor to account for summation and inhibition.

REFERENCES

1. Information on Levels of Environmental Noise Requisite To Protect Public Health and Welfare With an Adequate Margin of Safety. U.S. Environ. Prot. Agency, 550/9-74-004, Mar. 1974.

2. Schultz, Theodore J.: Synthesis of Social Surveys on Noise Annoyance. J. Acoust. Soc. America, vol. 64, no. 2, Aug. 1978, pp. 377-405.

3. Rice, C. G.: Development of Cumulative Noise Measure for the Prediction of General Annoyance in an Average Population. J. Sound & Vib., vol. 52, no. 3, June 1977, p. 345-364.

4. Powell, C. A.; and Rice, C. G.: Judgments of Aircraft Noise in a Traffic Noise Background. J. Sound & Vib., vol. 38, no. 1, January 1975, pp. 39-50.

5. Bottom, C. G.; and Waters, D. M.: A Survey Into the Annoyance Caused by Aircraft Noise and Road Traffic Noise. Loughborough Rep. TT 7204, Univ. Tech. [1972].

6. Grandjean, Etienne; Graf, Peter; Lauber, Anselm; Meier, Hans Peter; and Muller, Richard: A Survey of Aircraft Noise in Switzerland. Proceedings of the U.S. Environ. Prot. Agency, Internationl Congress on Noise as a Public Health Problem, 550/9-73-008, 1973, p. 645-659.

7. Powell, Clemans Ancelan, Jr.: Annoyance Due to the Interaction of Community Noise Sources. Sc. D. Diss., George Washington Univ., 1978.

8. Powell, Clemans A.: Laboratory Study of Annoyance to Combined Airplane and Road-Traffic Noise. NASA TP-1478, 1979.

9. Pearsons, Karl S.; and Bennett, Ricarda L.: Handbook of Noise Ratings. NASA CR-2376, 1974.

10. Stevens, S. S.: Power-Group Transformations Under Glare, Masking, and Recruitment. J. Acoust. Soc. America, vol. 39, no. 4, Apr. 1966, pp. 725-735.

11. Lockner, J. P. A.; and Burger, J. F.: Form of the Loudness Function in the Presence of Masking Noise. J. Acoust. Soc. America, vol. 33, no. 12, Dec. 1961, pp. 1705-1707.

12. Hellman, Rhona P.; and Zwislocki, J.: Loudness Function of a 1000-cps Tone in the Presence of a Masking Noise. J. Acoust. Soc. America, vol. 36, no. 9, Sept. 1964, pp. 1618-1627.

13. Ollerhead, J. B.: Predicting Public Reaction to Noise From Mixed Sources. Designing for Noise Control, William W. Lang, ed., Inter-Noise, 1978.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TP-1479		

4. Title and Subtitle	5. Report Date
A SUMMATION AND INHIBITION MODEL OF ANNOYANCE RESPONSE TO MULTIPLE COMMUNITY NOISE SOURCES	September 1979
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Clemans A. Powell	L-12978
	10. Work Unit No.
	505-09-13-11

9. Performing Organization Name and Address	11. Contract or Grant No.
NASA Langley Research Center Hampton, VA 23665	
	13. Type of Report and Period Covered
	Technical Paper

12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration Washington, DC 20546	

15. Supplementary Notes

16. Abstract

A model of annoyance due to combined noise sources has been developed. The model provides for the summation of the subjective magnitudes of annoyance due to the separate noise sources and for the inhibition of the subjective magnitudes of each source by the presence of the other noise sources. The inhibition process is assumed to mathematically obey a power-group transformation.

The results of an experiment in which subjects judged the annoyance of 15-minute sessions of combined aircraft and road-traffic noise are compared with the model herein developed and with several other models of combined source annoyance. These comparisons indicated that the model developed herein provides better qualitative and quantitative agreement with experimental responses than the other models. The application of the model to multiple community noises is discussed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Noise annoyance Aircraft annoyance Traffic annoyance Community response	Unclassified - Unlimited Subject Category 45

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	20	$4.00

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1979